

# Monophase Measurements on Prototype Pixel Structures

D. Bintinger, M. Gilchriese, J. Taylor and J. Wirth  
and contributions from

D. Cragg, E. Perrin and V. Vacek

May 1999

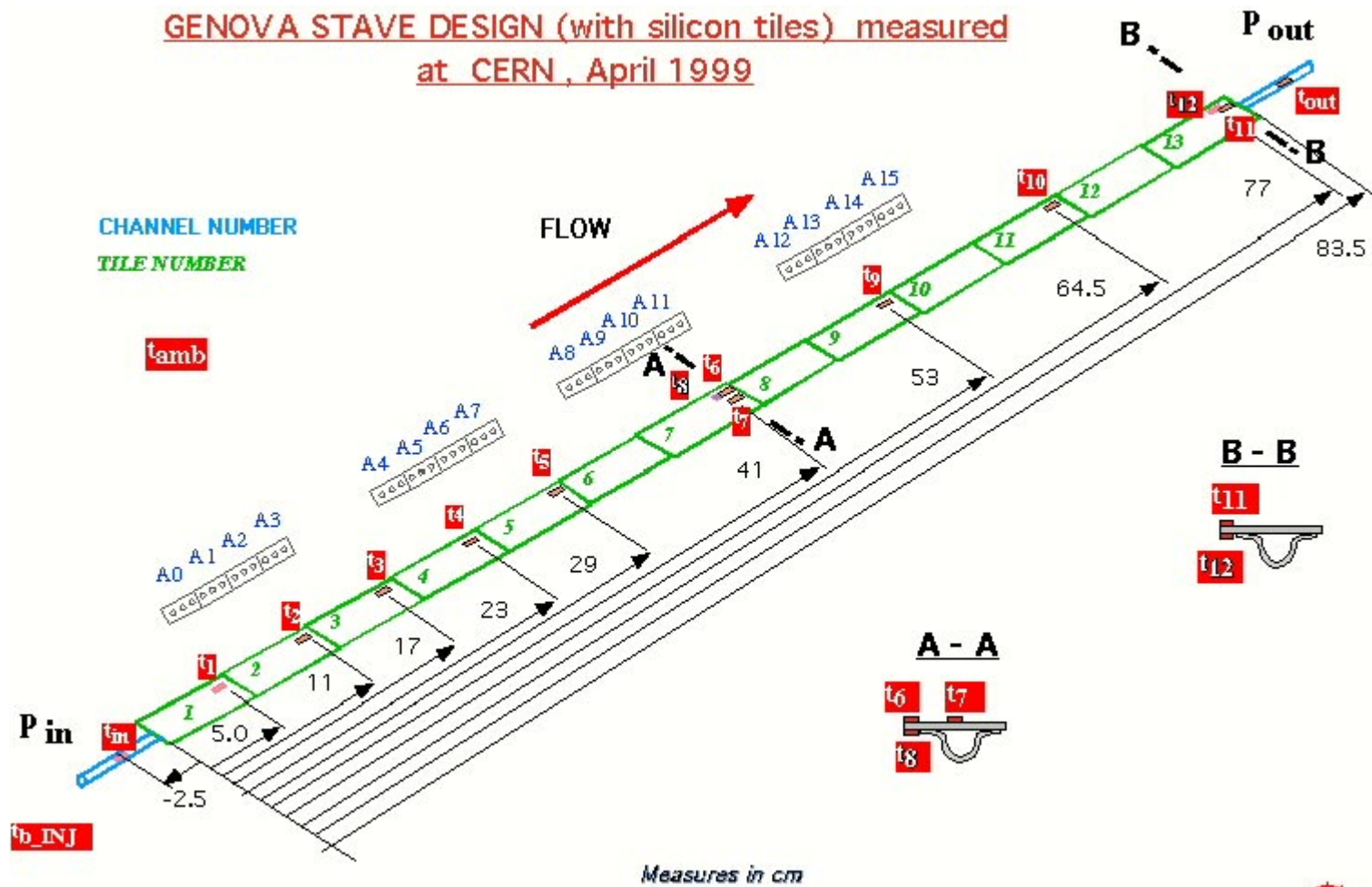
# Setup

- $C_6F_{14}$  cooled to about -25C or higher and circulated by pump.
- Pressure sensors on inlet and outlet(two types => two measurements)
- Temperature sensors on inlet/outlet and on stave structure
- Typical ambient temperature held at -10C.
- Measurements taken at
  - Different power - about{ 80(nominal), 100(“worst case”), 120 Watts }
  - Flows up to about 30 cc/s
  - Inlet temperatures down to about -25C
  - We normalize measurements taken with inlet T close to -20°C and -25°C to these values

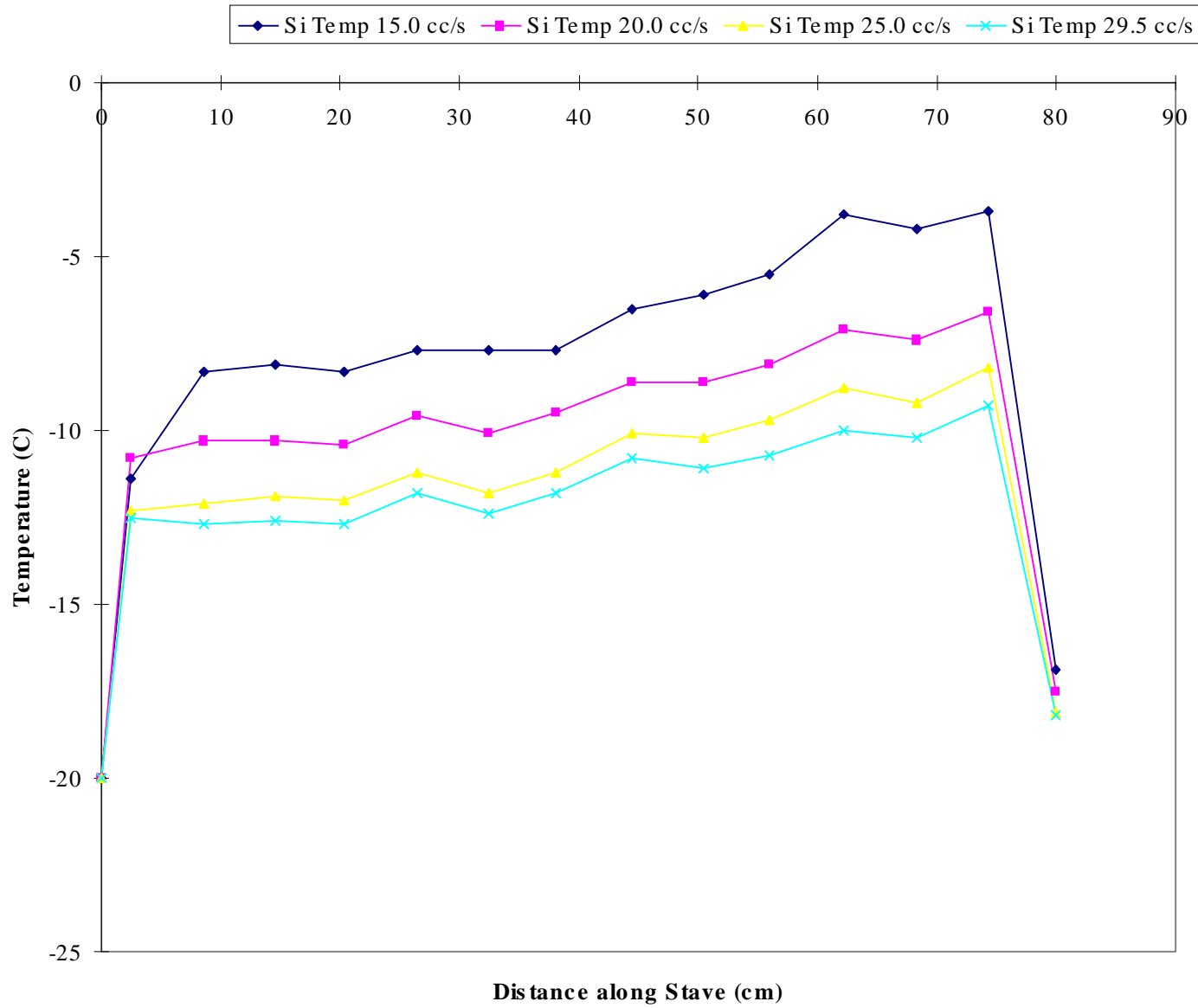


# Prototype Stave

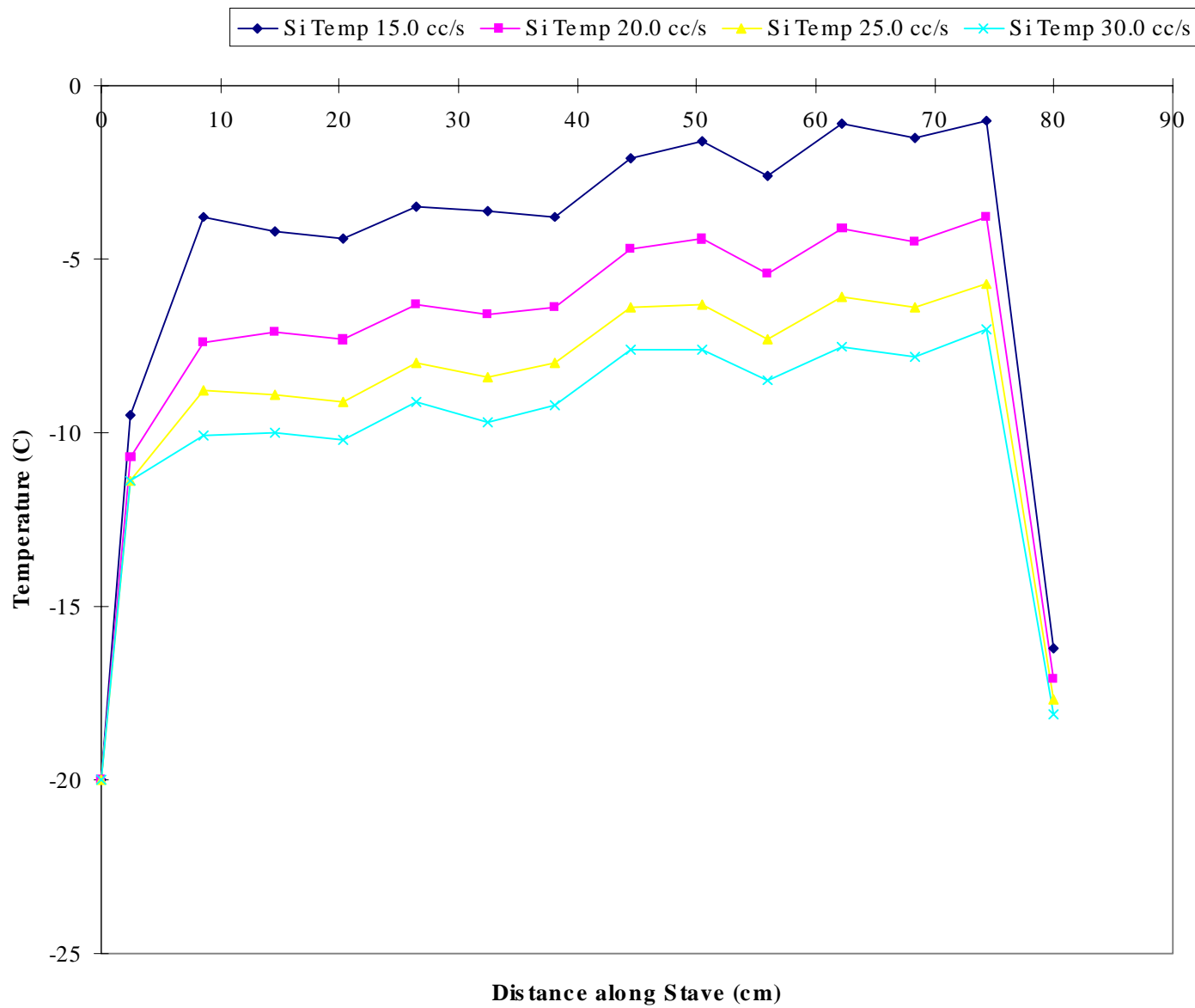
GENOVA STAVE DESIGN (with silicon tiles) measured  
at CERN, April 1999



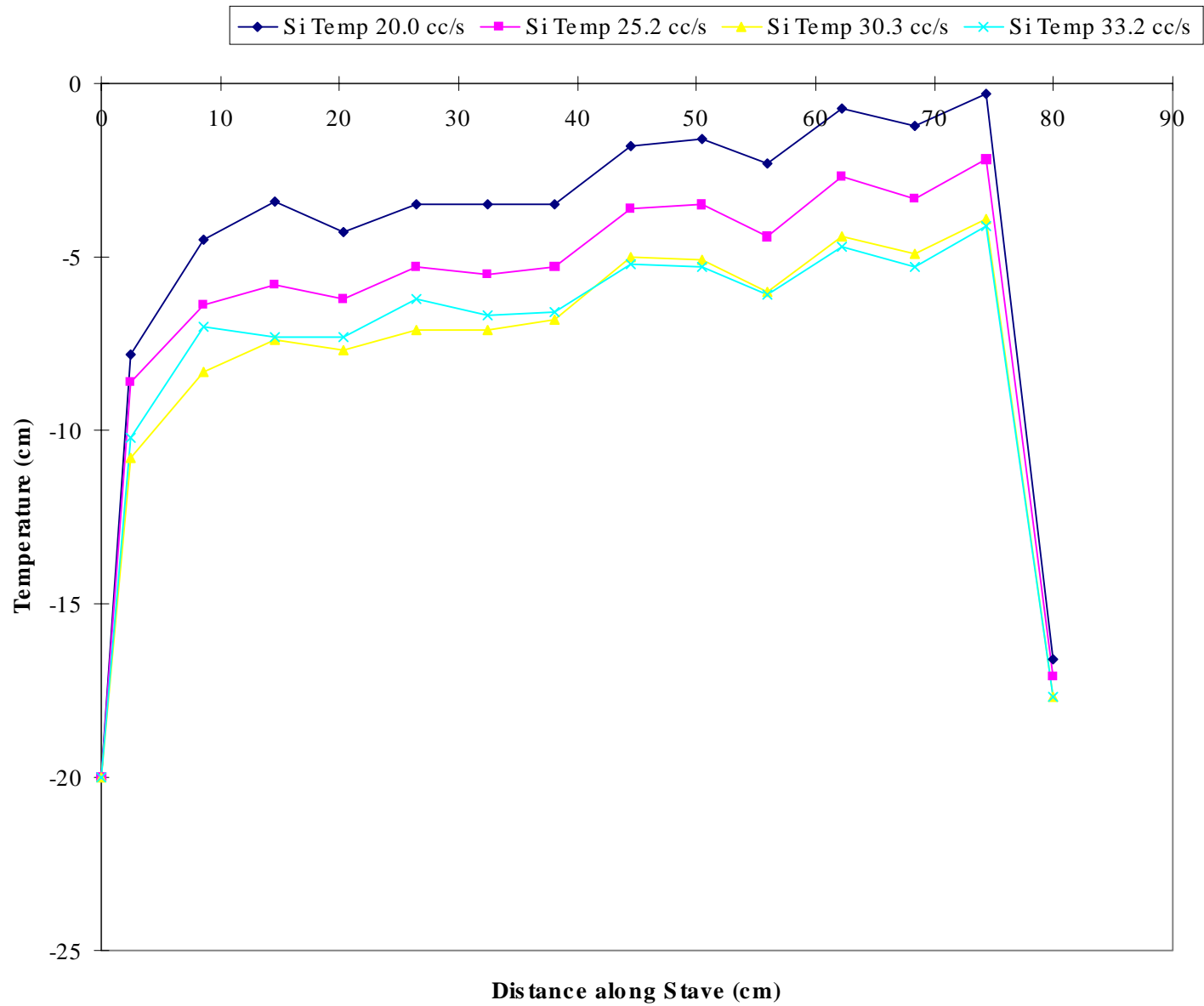
**Stave Temperature vs Distance, 80 Watts, Inlet=-20 C**



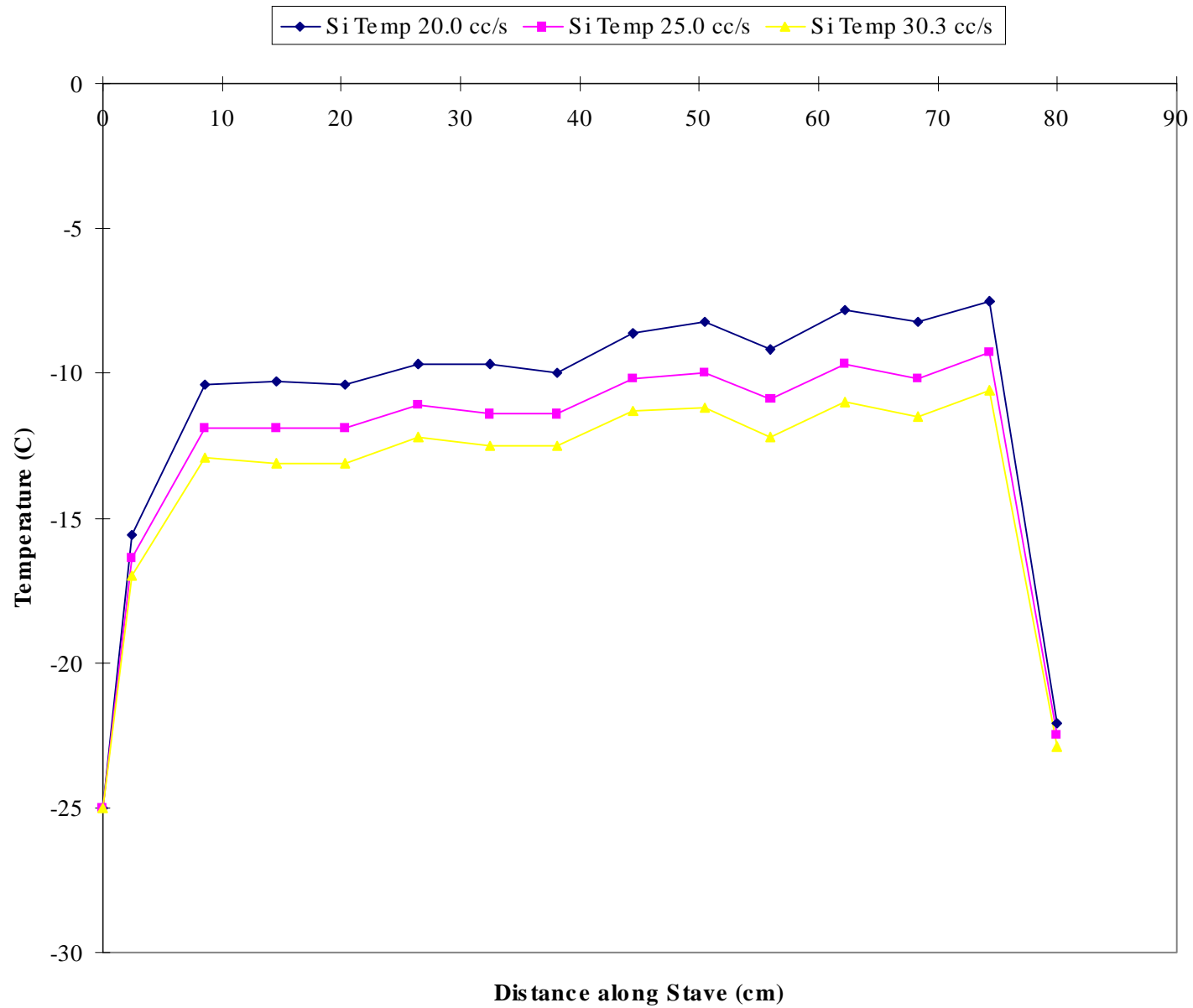
**Stave Temperature vs Distance, 102 Watts, Inlet=-20 C**



**Stave Temperature vs Distance, 123 Watts, Inlet=-20 C**



**Stave Temperature vs Distance, 103 Watts, Inlet=-25 C**



# Comparison With Calculations

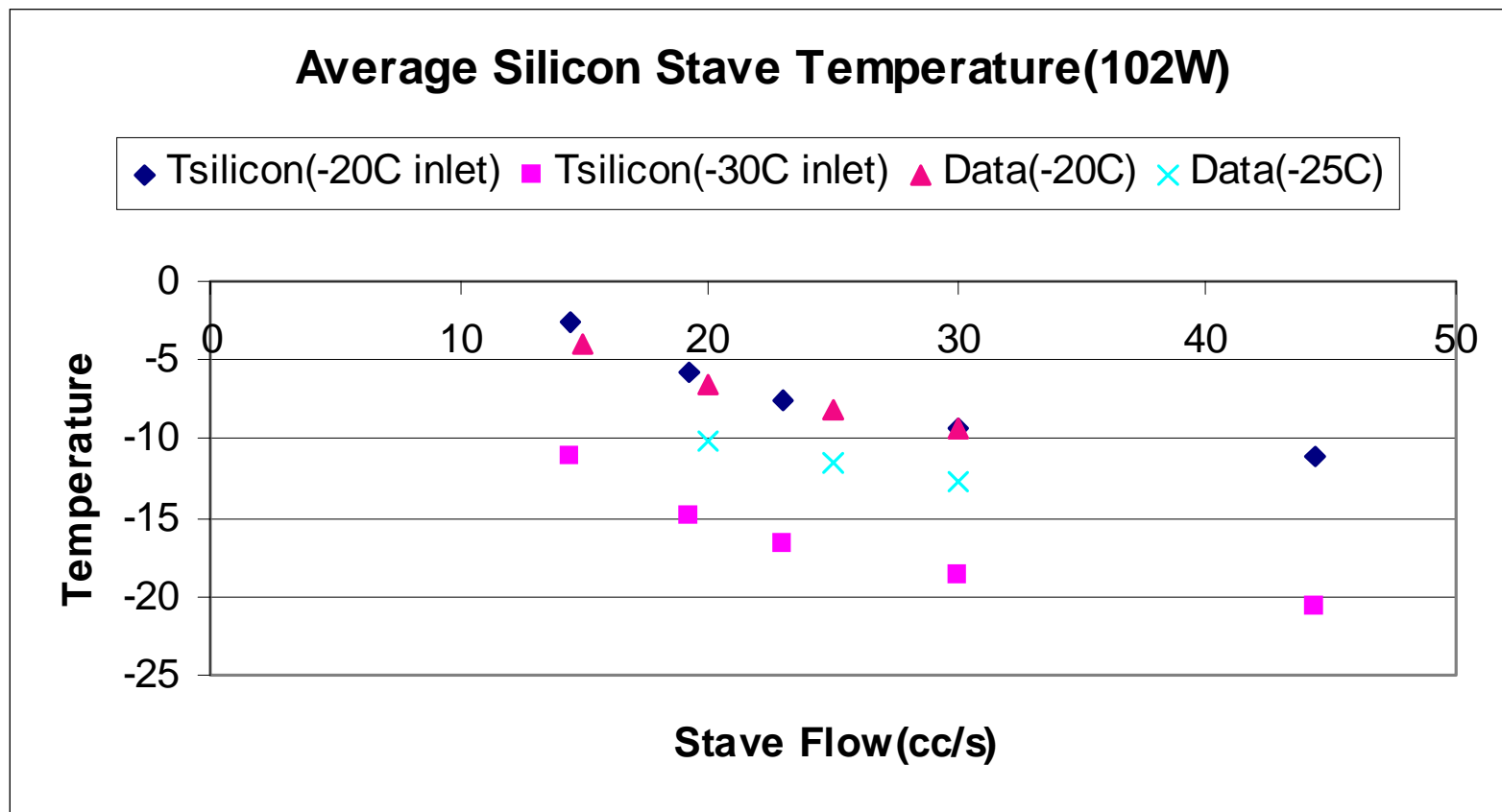
- Comparison made using  $C_6F_{14}$  properties as provided by 3M
  - Bulk fluid temperature rise passing through stave  $\Delta T_{\text{bulk}}$

POWER(WATTS)	FLOW(CC/S)	$\Delta T_{\text{BULK}}$ MEASURED	$\Delta T_{\text{BULK}}$ CALCULATED
81.7	19.8	2.4°C	2.3°C
101.8	25.0	2.3°C	2.3°C
123.0	30.3	2.3°C	2.3°C

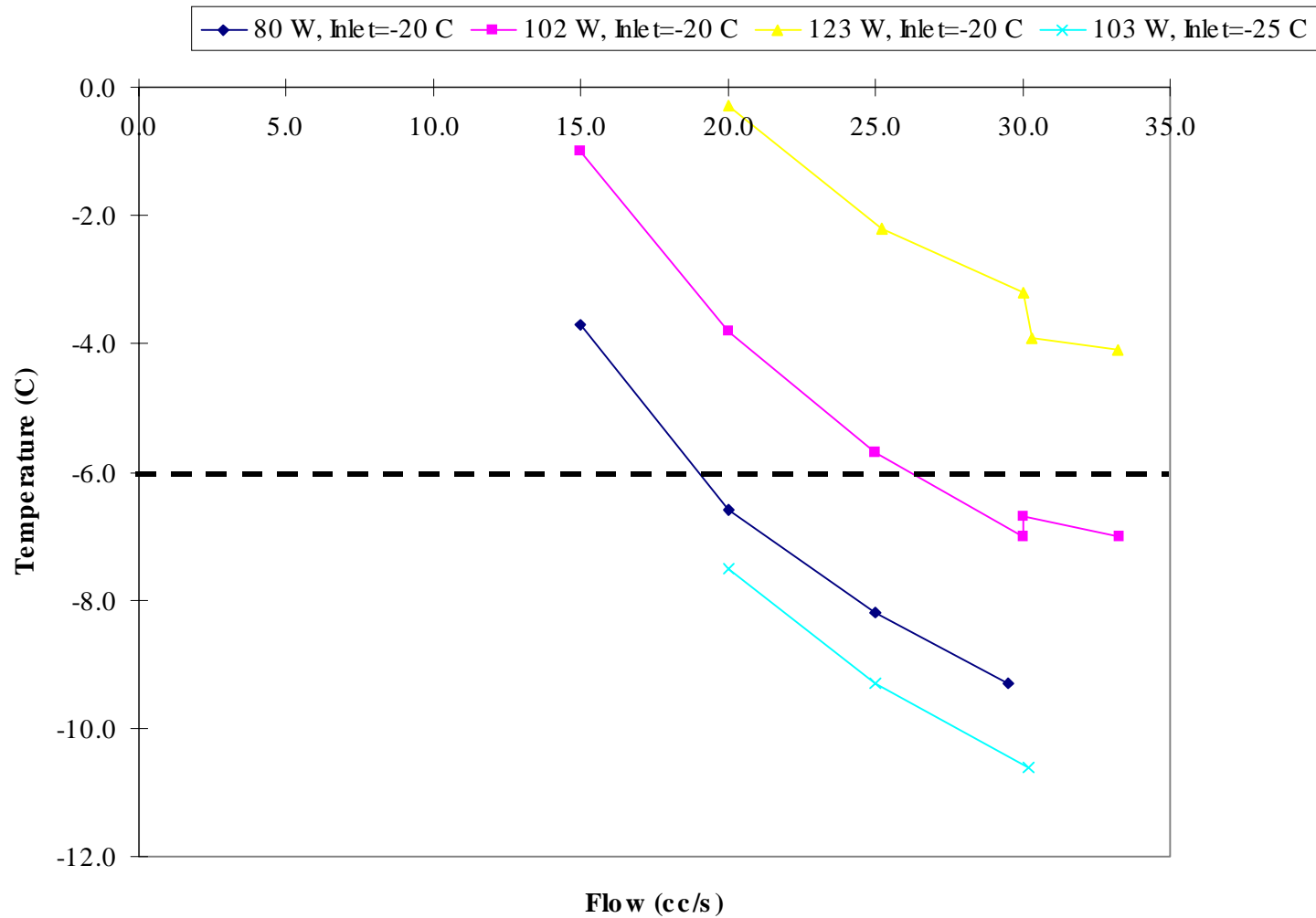
- At power of 102 W and flow of 30 cc/s, the measured “silicon” temperature at the center of a stave is -9.3°C for inlet temperature of -20°C.
- Bintinger and Vaclav using Gnielinski’s equation predict the wall of the cooling tube to be at -13.6°C. (A local heat transfer coefficient of 3600 W/m<sup>2</sup>K is implied.) The difference of 4.3°C is attributed to the temperature drop across the stave structure and is in good agreement with FEA estimate of 3.9°C.
- To compare with measurements, we use the 4.3°C drop to add to the calculated value - see next page.
- Calculations were done at -20°C and -30°C and measurements were taken with inlet temperatures close to -20°C and -25°C and then corrected to these values.

# Calculated Temperature and Measurements

- Tsilicon calculated at center of stave assuming 4.3°C gradient in stave structure

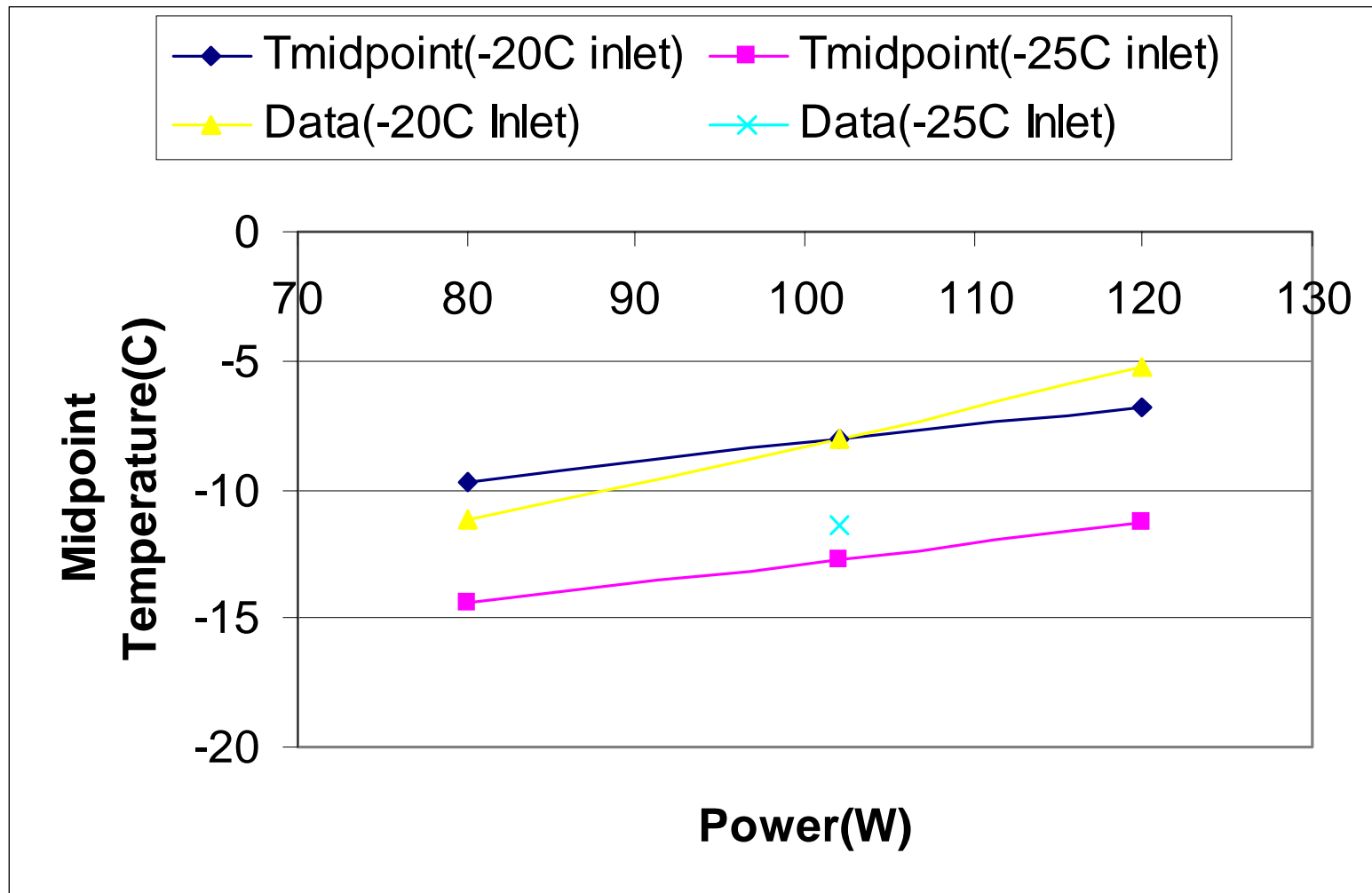


## Maximum Silicon Temperature vs Power and C6F14 Flow



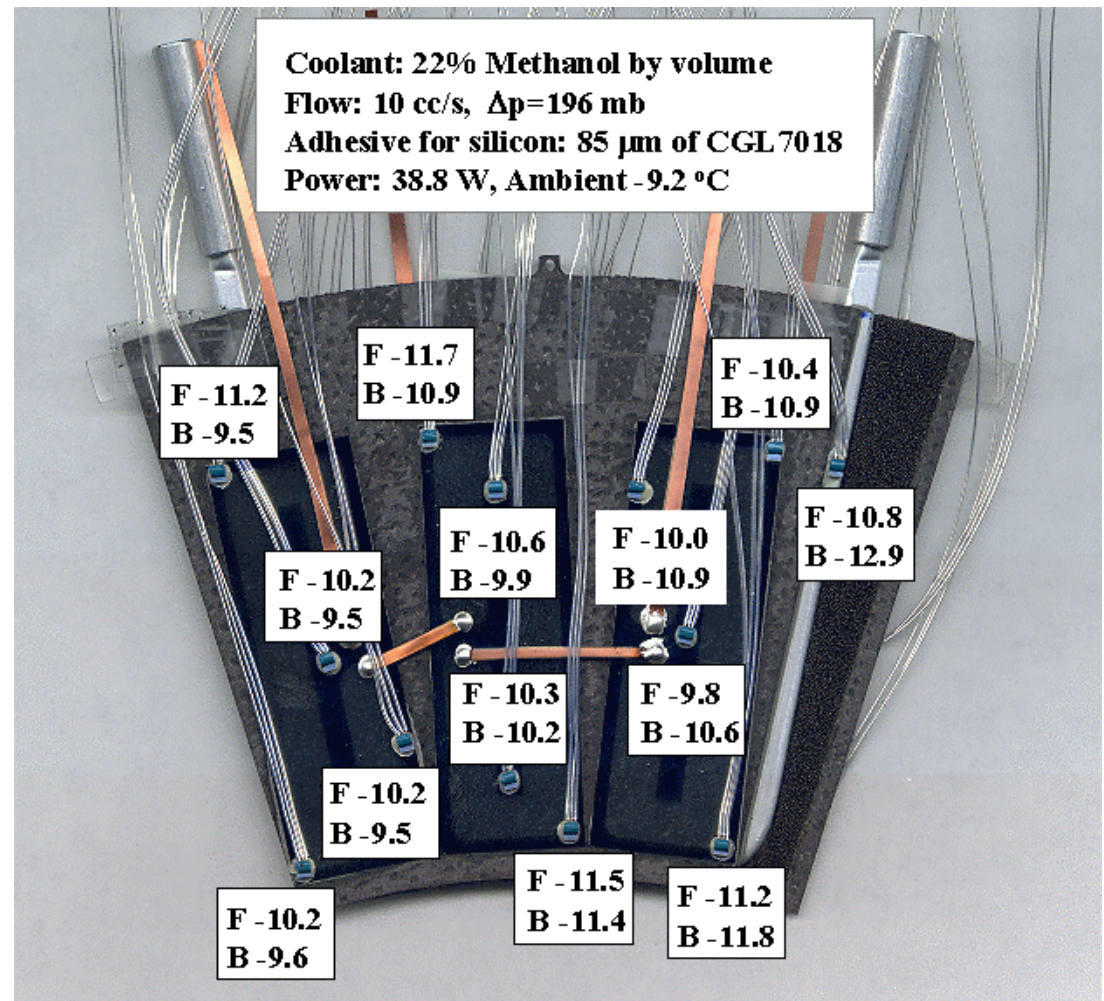
For a power of	80W and inlet T of	-20C we need flow of	>18 cc/s
For a power of	102W and inlet T of	-20C we need flow of	>26 cc/s
For a power of	102W and inlet T of	-25C we need flow of	> about 16 cc/s
For a power of	123W and inlet T of	-20C we need flow of	> about 45 cc/s
For a power of	123W and inlet T of	-25C we need flow of	> about 30 cc/s

## Calculated Midpoint Stave Temperature vs Power for 25 cc/s Flow and Comparison with Data



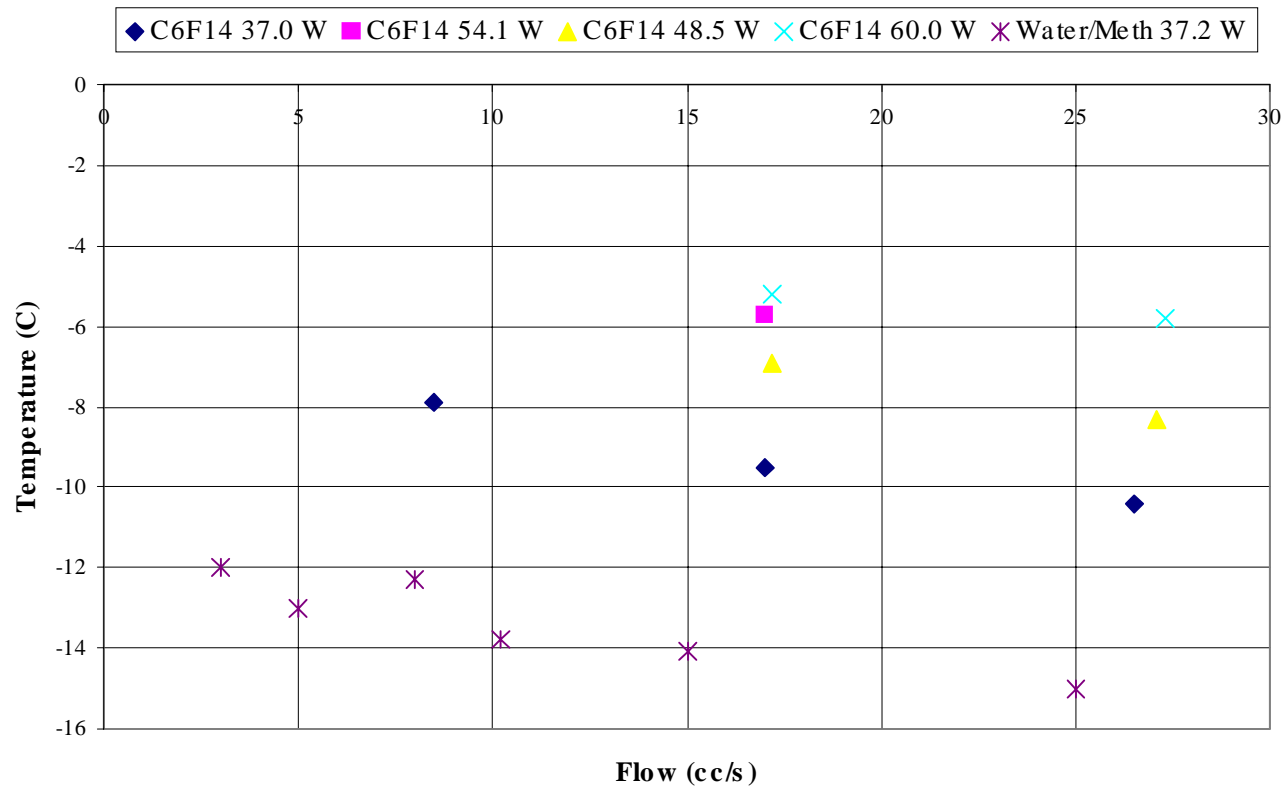
# Pixel Sector Prototype

- Temperature measurements using liquid  $C_6F_{14}$  were done on prototype sector previously measured using water-methanol.
- The maximum temperature for different power and flow conditions is given on the next page.



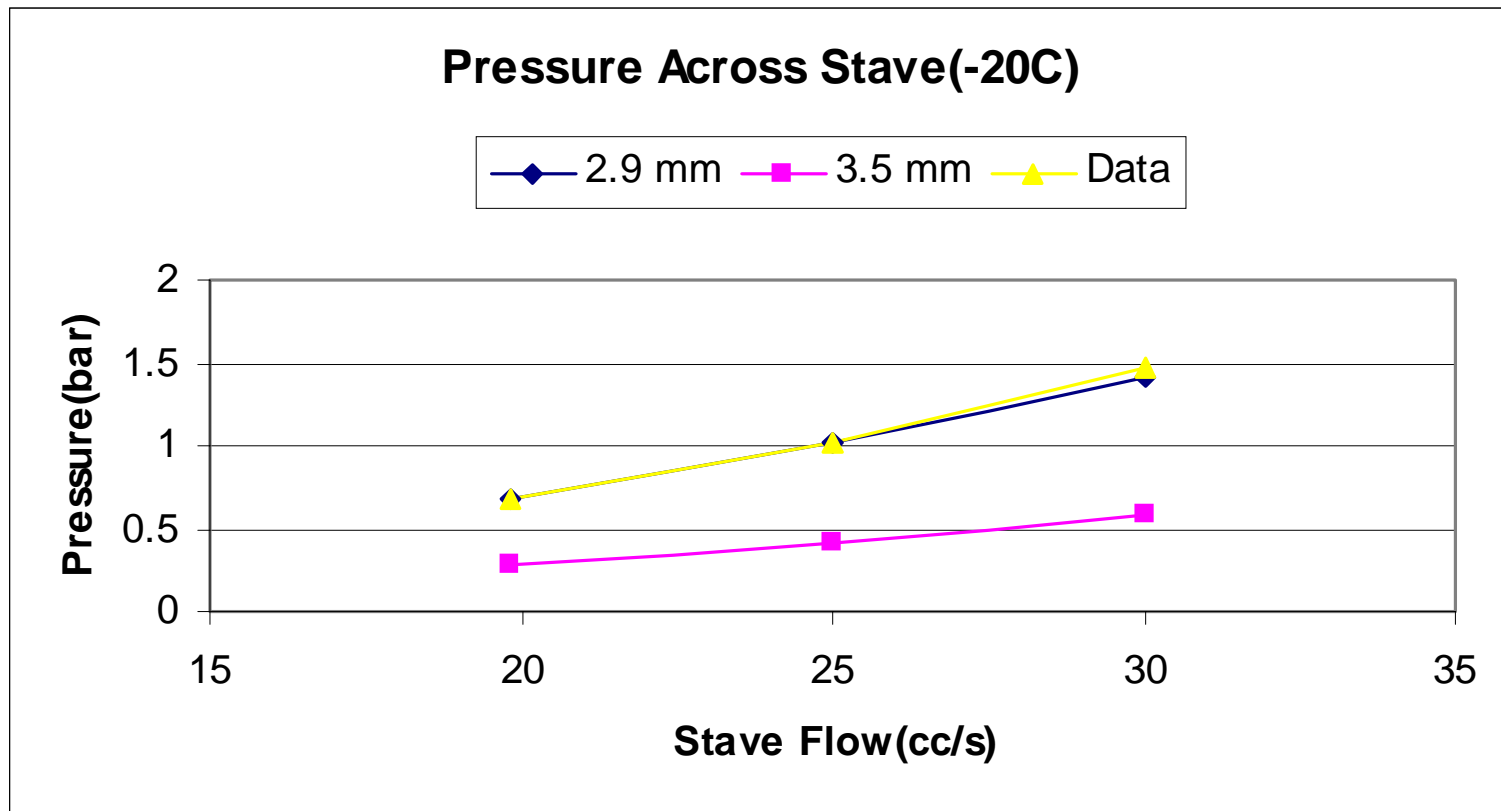
# Maximum Observed Temperature on Pixel Sector vs Power and Flow of C<sub>6</sub>F<sub>14</sub>

Highest Temperature vs Flow, Al Tube Sector 3, Inlet = -20 C



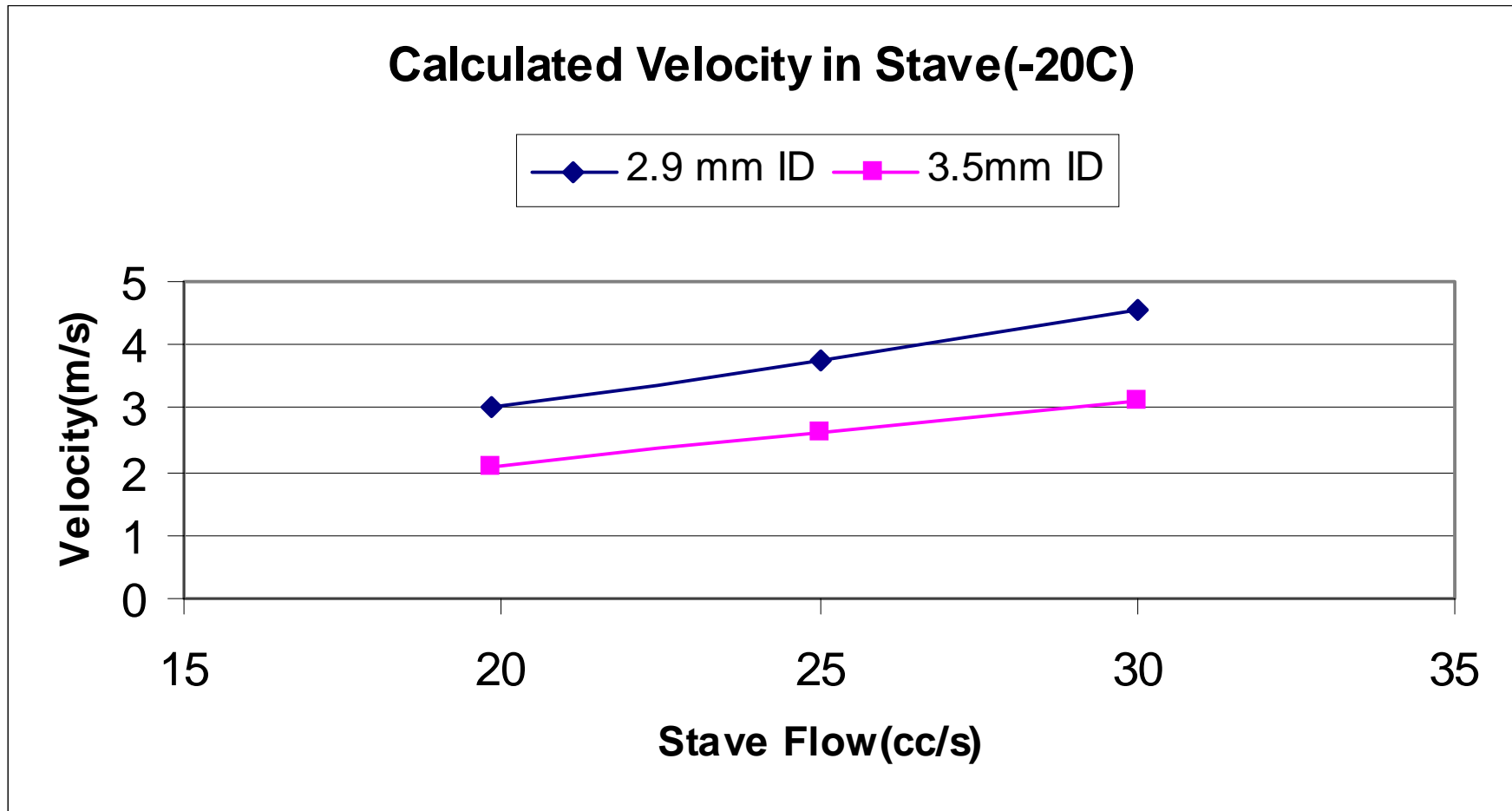
For a power of	36W and inlet T of	-20C we need flow of	>5 cc/s
For a power of	48W and inlet T of	-20C we need flow of	>13 cc/s
For a power of	60W and inlet T of	-25C we need flow of	>about 8 cc/s

# Pressure Drop in Stave vs Flow



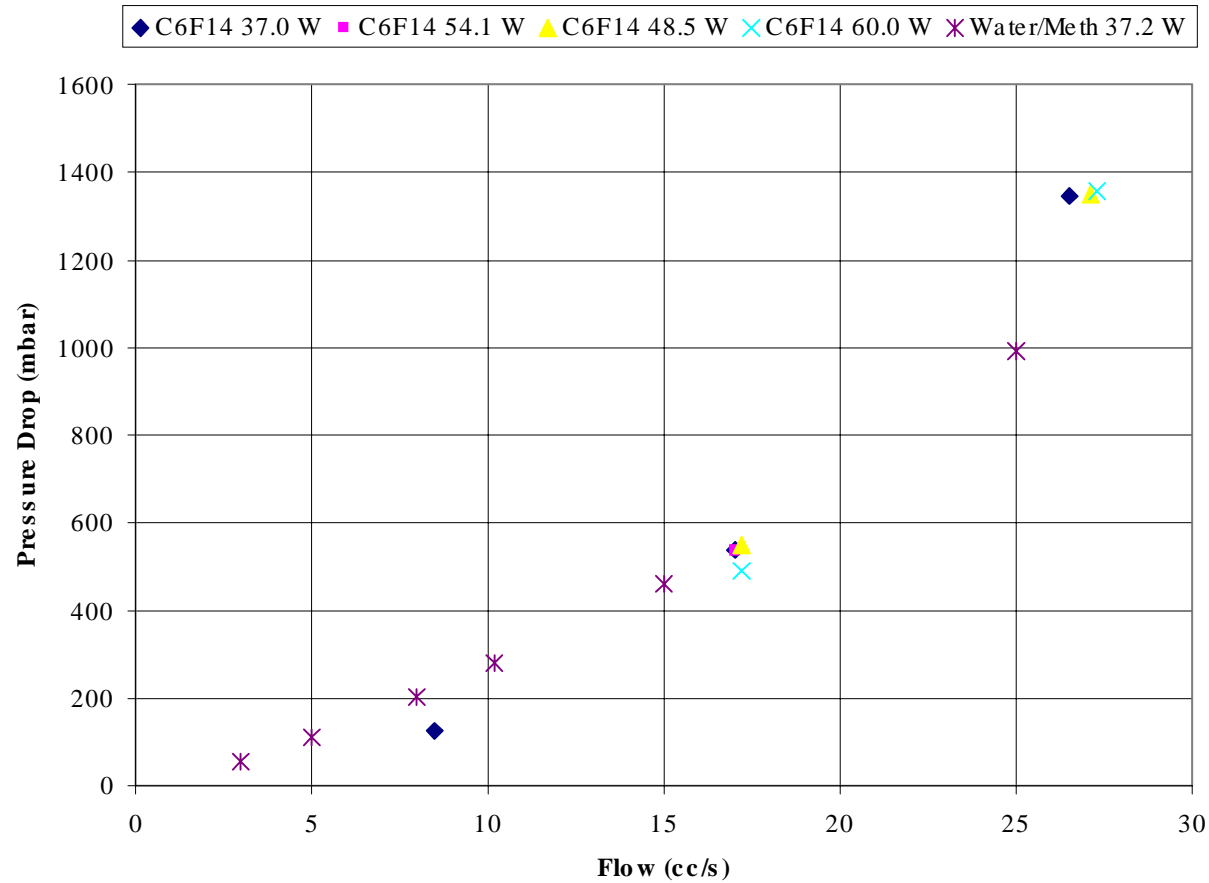
- We derive an effective hydraulic diameter of about 2.9 mm for the stave from measurements. The effects of inlet and outlet tubing(16cm of 3.5 mm ID) were removed(by calculation) to obtain the pressure across the stave.
- The plot above shows data and calculation for 2.9 mm hydraulic diameter and a calculation for 3.5mm hydraulic diameter.

# Calculated Velocity in Stave vs Flow



# Pressure Drop in Sector vs Flow

Pressure Drop vs Flow, Al Tube Sector 3, -20 C

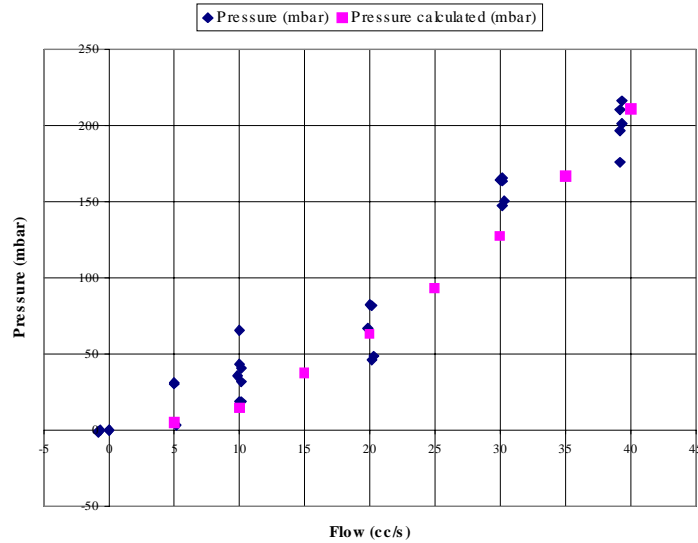


- The inner dimension of the sector tube are approximately 2.1 mm x 4.1 mm with 5 tight U bends.

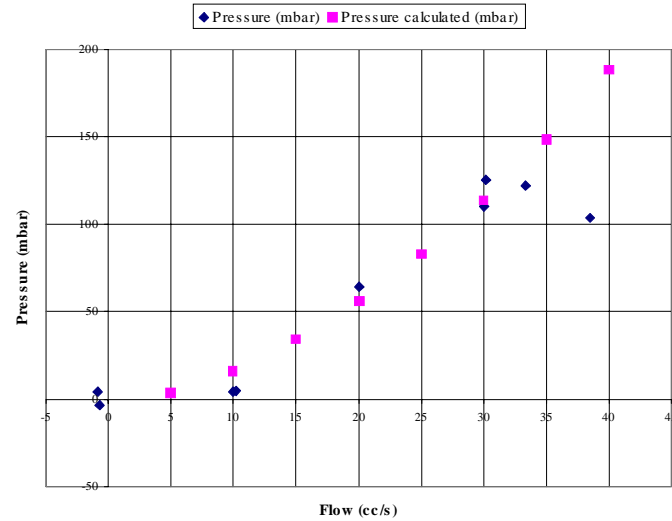
# Pressure Measurements in Long Tube

- Pressure measurements were made on a 3m long copper tube with 6.35mm ID to compare with calculations

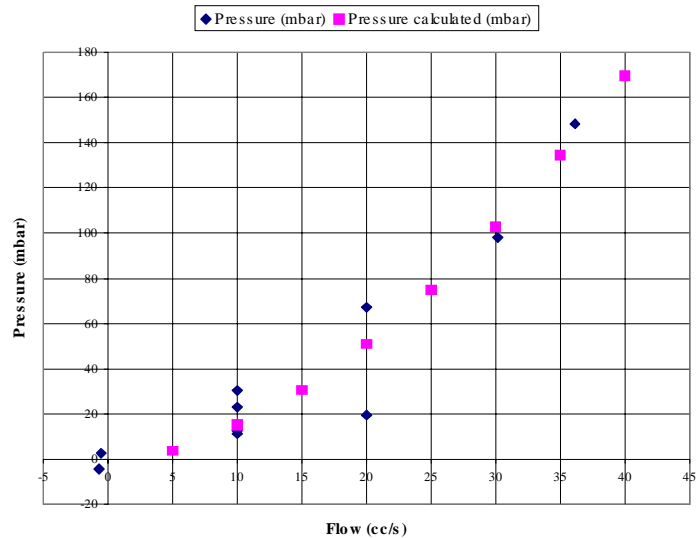
Pressure vs Flow, C6F14, 3 m tube, 6.35 mm id, -20 C



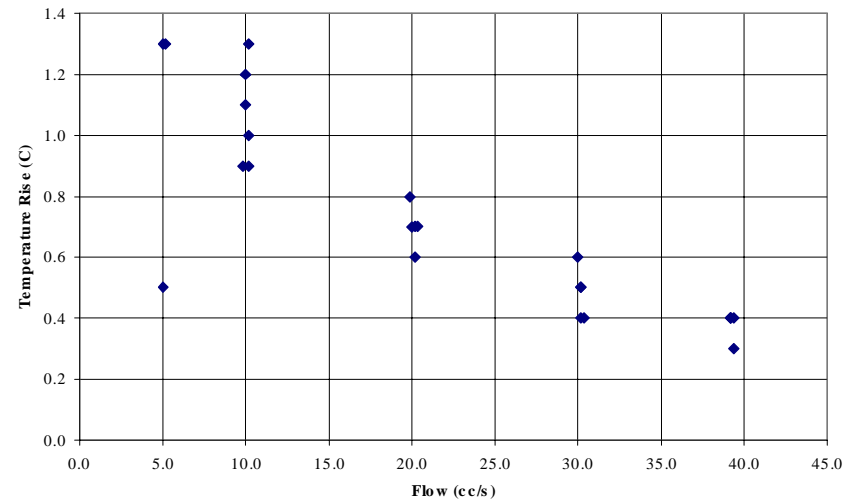
Pressure vs Flow, C6F14, 3 m tube, 6.35 mm id, 0 C



Pressure vs Flow, C6F14, 3 m tube, 6.35 mm id, +20 C



Temperature Rise vs C6F14 Flow for 3.6 m of insulated Cu 6.35 mm id tubing, Fluid Temp. = -17 C, Ambient = +18 C, Insulation was 12 mm thick foam.



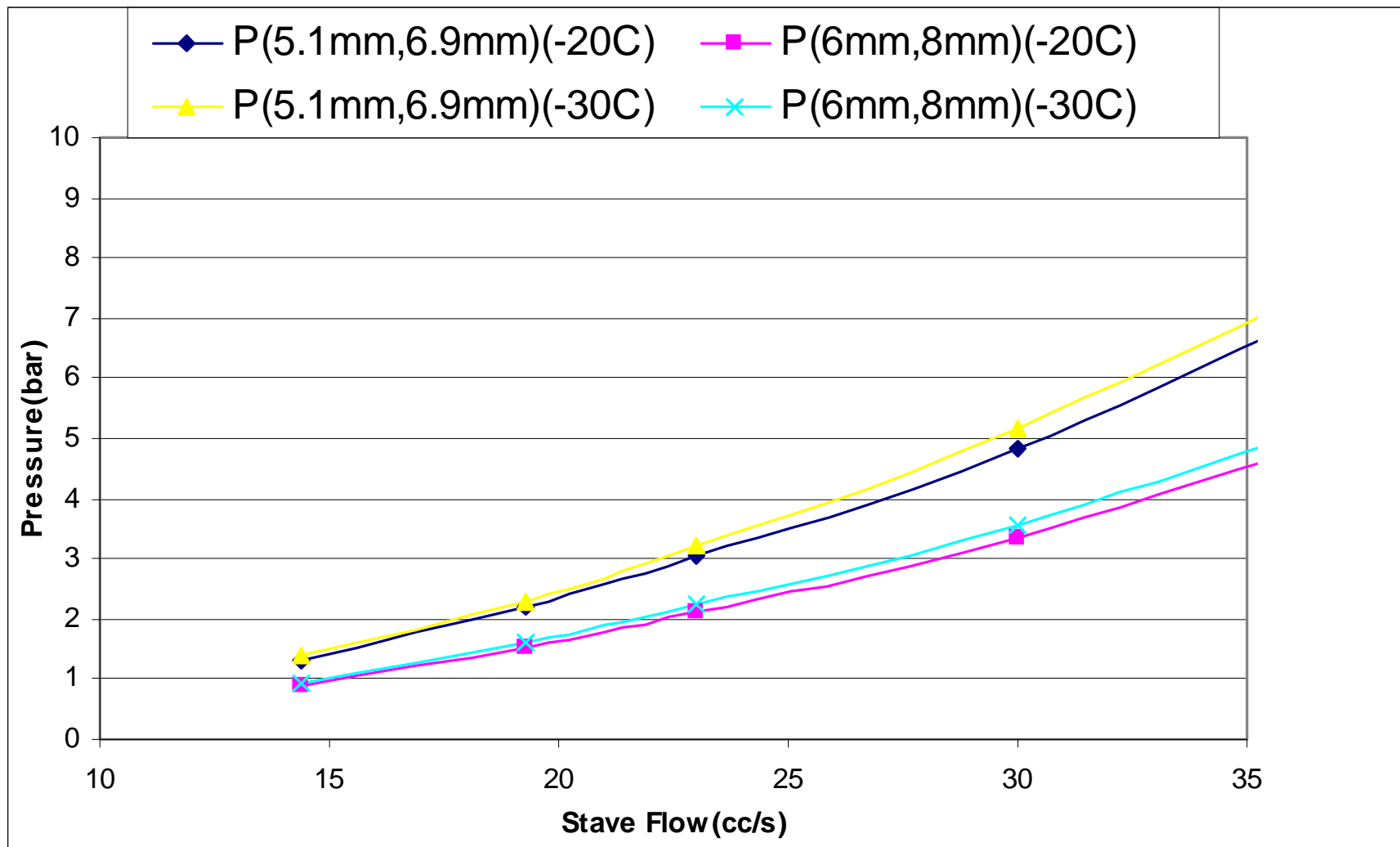
## Total Circuit Pressure

- Using the effective hydraulic diameter of 2.9mm for the stave and inlet/outlet tubing sizes and routing(bends), the total circuit pressure from and to PPB3 was calculated.
- Two different piping configurations were compared(IDs shown below)

	<u>Baseline Layout</u>	<u>“Maximum” Layout</u>
Pixel->PPB1	5.1mm	6.0mm
PPB1->PPB2	6.9mm	8.0mm
PPB2->PPB3	13mm	13mm

- Two staves per circuit are assumed.
- Little difference in pressure for colder fluid - see plot next page
- Head pressure(about 6.1m = 1bar) or effect of operating closed system must be added(or subtracted) from circuit pressure shown.
- Circuit pressure calculations were compared to those of D. Cragg and agreed to 2-3%.

## Circuit Pressure vs Stave Flow



## Other Considerations

- $C_6F_{14}$  (or any fluorinert) is a degreasing agent. We tested the following thermal greases for resistance to immersion in  $C_6F_{14}$ .

AI Technology CGL 7018                      no effect up to 24 hours(stopped)

Dow Corning DC340                      no effect up to 24 hours(stopped)

Thermagon T431 Sil-less Grease                      no effect up to 24 hours(stopped)

- The radiation length of  $C_6F_{14}$  is 19.3 cm at  $-20^{\circ}\text{C}$ . Compared to evaporative  $C_4F_{10}$  as estimated in the Pixel TDR, using liquid  $C_6F_{14}$  would add about 0.2%  $X_0$  per barrel layer at normal incidence.
- All flow with  $C_6F_{14}$  is turbulent.
- If the stave hydraulic diameter were increased, the fluid velocity would decrease and the film temperature gradient is predicted to increase. With a hydraulic diameter of 2.9 mm, the pressure drop across the stave is a significant fraction of the total circuit pressure.

# Summary for Stave

- For baseline pipe sizes(5.1, 6.9, 13 mm ID)
  - For -20°C inlet temperature
    - 80W stave power => 2.2 bar circuit pressure
    - 100 W => 4.0 bar
    - 120 W => big number
  - For -25°C inlet temperature
    - 80W stave power => <1 bar circuit pressure
    - 100 W => 1.5 bar
    - 120 W => 4.2
- For maximum pipe sizes(6.0, 8.0, 13 mm ID)
  - For -20°C inlet temperature
    - 80W stave power => 1.5 bar circuit pressure
    - 100 W => 2.5 bar
    - 120 W => big number
  - For -25°C inlet temperature
    - 80W stave power => <1 bar circuit pressure
    - 100 W => 1.0 bar
    - 120 W => 2.9
- The circuit pressure at the stave is one-half of the circuit pressure

# Conclusions

- Prototype pixel stave and sector structures have been successfully cooled with liquid  $C_6F_{14}$
- Calculations using fluid properties are in reasonable agreement with measurements of pressures and temperatures and can be used with some confidence to predict system performance.
- For a stave power of about 90W, an inlet temperature of -20°C or less is necessary to provide cooling at a reasonable circuit pressure (about 3 bar) with current piping sizes.
- For the same power density on the sector the flow requirements are lower and hence the circuit pressures will be less.
- Higher stave power than about 100W implies higher pressure operation, lower inlet temperatures or bigger piping or some combination of these to meet temperature requirements.